

Prediction of Geometric Nonlinear Steady Flight Loads via extended Modal Rotation Method

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ABSTRACT

The goal of higher fuel efficiency and lower emissions has led to significant changes in aircraft design in the aerospace industry over the past decades. From an aerodynamic perspective, increased performance is mainly associated with a reduction of induced drag achieved by an increase of wing aspect ratio. In structural design, the objective is to minimize structural mass, which has led to increased use of composite materials in load-carrying components. Combining these measures from different disciplines results in very slender and highly flexible structures [1]. Therefore, the occurring geometric nonlinear effects due to large deformations have to be considered in coupled aeroelastic analyses during the design process. Since conventional aeroelastic software packages, such as MSC Nastran, are still based on linear structural dynamics, these may no longer be suitable to describe the behavior of very flexible flight vehicle configurations. Hence, recent developments of aeroelastic software frameworks employ reduced order models with nonlinear beam theories [2] or nonlinear normal modes [3]. While these methods were specifically designed to capture the effects due to geometric nonlinearities, they usually require a preprocessing step for the calculation of nonlinear modes or the identification of an equivalent beam model respectively. Depending on the level of automation of the process, this can represent a limitation in terms of its utilization in aeroelastic optimization if additional user input and effort is required after each optimization loop.

In this paper, a novel approach for the prediction of geometric nonlinear steady flight loads will be presented. Therefore, the Modal Rotation Method (MRM) presented by Drachinsky et al. [4] is implemented in *pyUVLM*, an inhouse aeroelastic simulation framework developed at the DLR Institute of Aeroelasticity. In general, the MRM is formulated for clamped structures, dividing these into a number of small segments along a predefined reference line along the wing. The geometric nonlinear deformation field is calculated using the modal rotations obtained from linear modal analysis by sequentially computing the displacements of each segment. An update of the stiffness matrix due to geometric stiffening is accounted for by an iterative load-correction procedure. This correction, however, poses a computationally intensive bottleneck, as it requires the evaluation of section loads with respect to the deformed shape of each segment. Hence, the original formulation of the MRM is adapted to minimize the number of calculations required for load correction and to enable the utilization of loads reference axis models, resulting in a significant reduction in computation time. Results for the original and adapted formulation of the MRM will be shown for a slender composite wing box model (see Fig. 1) under different loading conditions and validated with reference results obtained from the geometrically nonlinear solution sequence SOL400 in MSC Nastran. Afterwards, the MRM is further extended for integration within the nonlinear aeroelastic trim solver of *pyUVLM*, which employs a geometrically nonlinear vortex lattice implementation. Finally, the developed framework is used for steady flight load predictions of the TUFlex very flexible flying demonstrator [5, 6] (see Fig. 2). Two configurations with different levels of

flexibility will be investigated. The results for approximately 20 different load cases obtained from the MRM will be compared to results using the conventional linear modal approach and the critical load cases will further be compared to reference results obtained with Nastran SOL400.

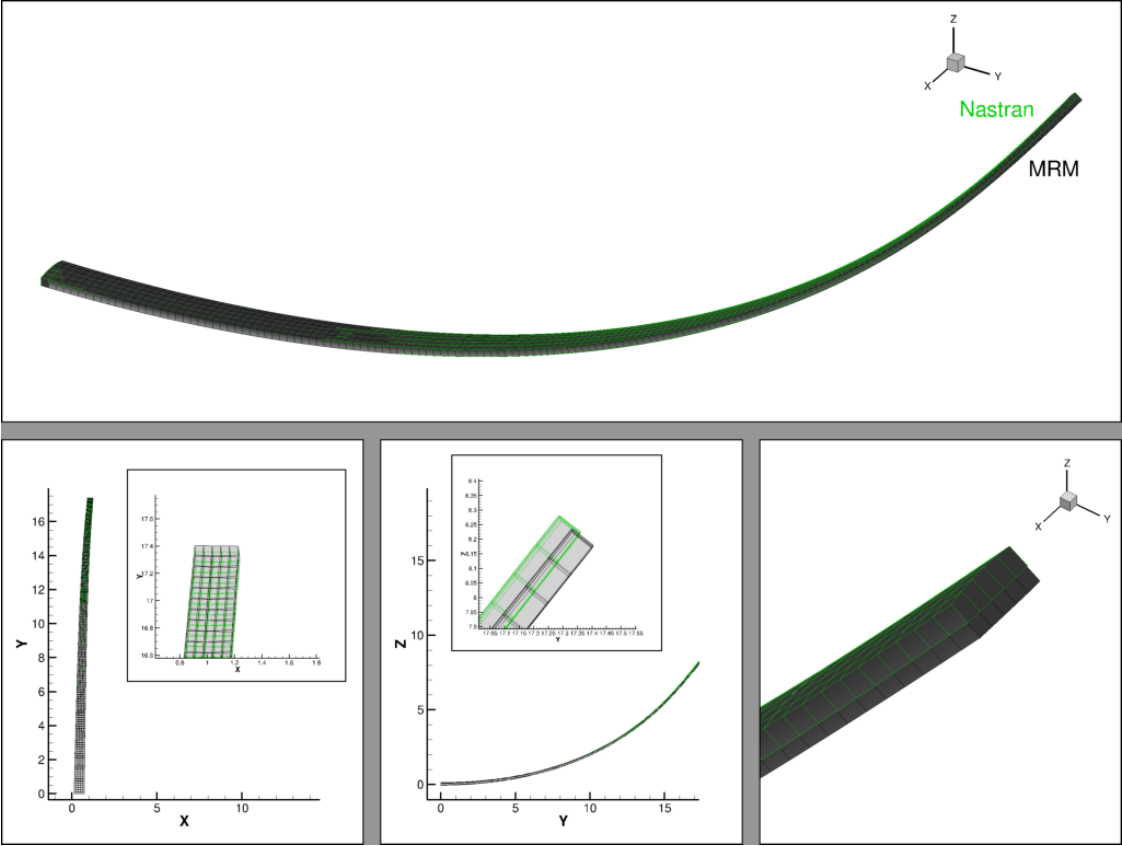


Figure 1: Slender composite wing box test case results comparison between MRM and MSC Nastran SOL400

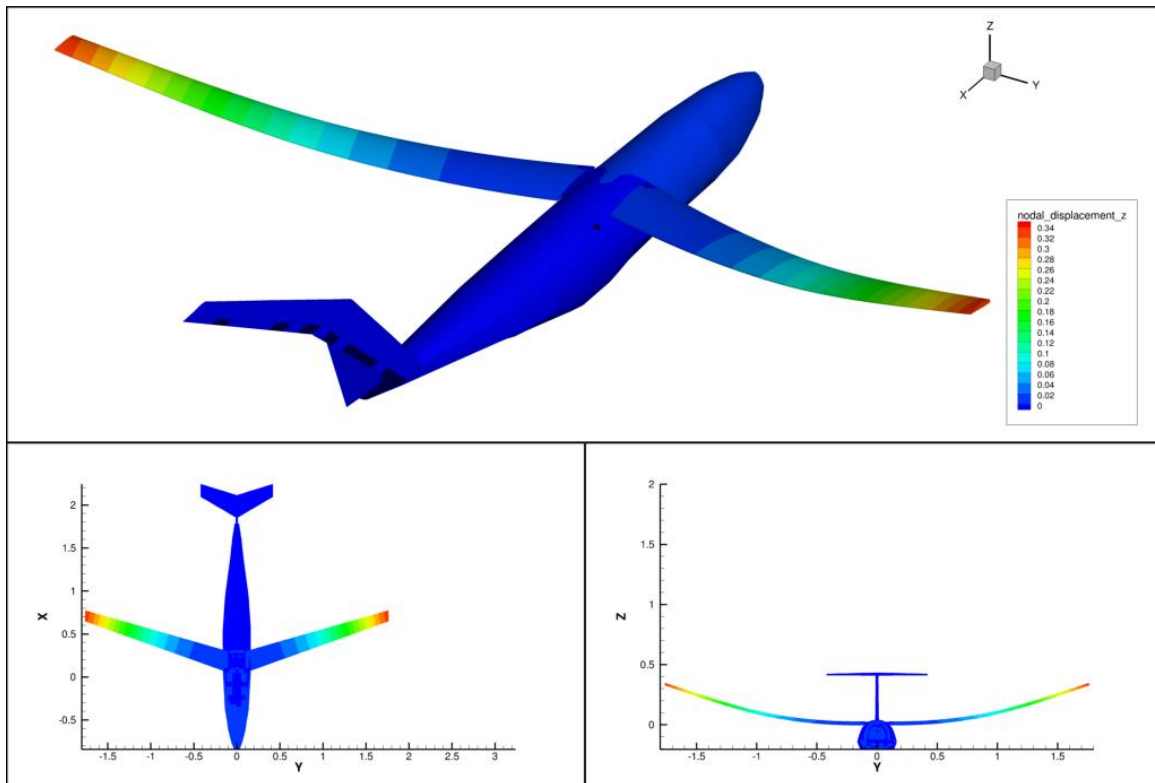


Figure 2: MRM Results for TUFlex test case for 4g pull up maneuver exhibiting moderate wing tip deflections

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